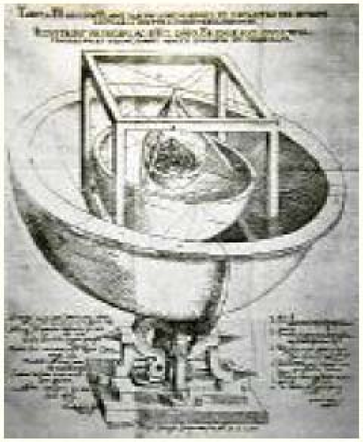
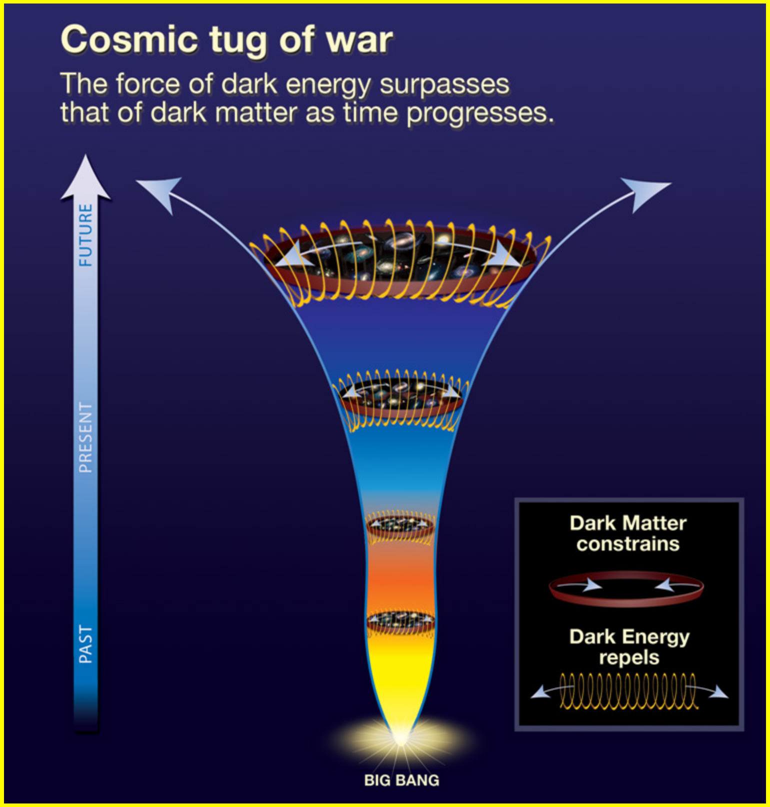

A BIG PUZZLE :
OUR UNIVERSE
AND US

Intelligent Design

God as „Master Architect“
Bible moralisée, 13th cent.



“Mysterium Cosmographicum”
Johannes Kepler, Graz, 1596



Life on Earth is not only brief, but dismaying tenous.

We were attached (luckily) to a favoured evolutionary line

HOW TO BUILD A UNIVERSE

THE FAMILIAR CANONICAL PICTURE

- The abundance distribution was interpreted, starting from Burbidge, Burbidge, Fowler and Hoyle(1957), as the outcome of a few basic processes of nucleosynthesis.
- H burning (the most effective, with an average of 7MeV per nucleon of generated energy): produced ^{4}He, ^{3}He, and gives (generally secondary) contributions to intermediate nuclei up to Si.
- He burning (the second-most effective): produces ^{12}C, ^{16}O, some ^{20}Ne, plus secondary chains starting from ^{14}N or ^{13}C and leading to neutron generation.
- Fusion of intermediate nuclei -^{12}C, ^{16}O, (^{20}Ne), (^{28}Si)$\rightarrow$nuclei below and up to the Fe-peak.
- Nuclear statistical equilibrium processes leading to ^{56}Fe -^{56}Ni and beyond, before and after the explosion.
- Explosive nucleosynthesis in SN shells, reorganizing abundances up to $^{63,65}Cu$
- Explosive nucleosynthesis in themonuclear SN Ia ($\rightarrow$Fe).
- Neutron captures (slow and rapid processes).
- Rare p-processes (γ-induced?)

Stable beam program for the Nuclear Astrophysics

Key problems:

Scientific program
Links between different branches of Physics
Nuclear reactions to be measured

Synthesis of Heavy Elements

At high tempreatures a larger number of nuclear reactions are activated

C-burning $T \sim 10^9$ K

$^{12}C(^{12}C,\alpha)^{20}Ne$
$^{12}C(^{12}C,p)^{23}Ne$

$^{12}C(p,\gamma)^{13}N(\beta^+)^{13}C(\alpha,n)^{16}O$ $^{12}C(n,\gamma)^{13}C(\alpha,n)^{16}O$
$^{25}Mg(n,\gamma)^{26}Mg(p,\gamma)^{27}Al$
$^{16}O(\alpha,\gamma)^{20}Ne$
$^{20}Ne(n,\gamma)^{21}Ne$

$^{16}O(\alpha,\gamma)^{20}Ne$
$^{12}C(^{12}C,\alpha)^{20}Ne$
$^{12}C(^{12}C,p)^{23}Na$ — $(p,\alpha)^{20}Ne$ / $(p,\gamma)^{24}Mg$ / $(\alpha,p)^{26}Mg$
$^{22}Ne(\alpha,n)^{25}Mg(p,\gamma)^{26}Al(\beta^+)^{26}Mg(p,\gamma)^{27}Al$
$^{22}Ne(p,\gamma)^{23}Na$
$^{20}Ne(n,\gamma)^{21}Ne(\alpha,n)^{24}Mg$
$^{20}Ne(\alpha,\gamma)^{24}Mg$
$^{12}C(n,\gamma)^{13}C(\alpha,n)^{16}O$

Ne-burning $T \sim 1.3 \cdot 10^9$ K

$^{20}Ne(\gamma,\alpha)^{16}O$

$^{20}Ne(\alpha,\gamma)$ / $^{21}Ne(\alpha,n)$ → ^{24}Mg → (α,γ) / $(n,\gamma)^{25}Mg(\alpha,n)$ → $^{28}Si(\alpha,\gamma)^{32}S$

^{23}Na → $(\alpha,p)^{26}Mg$ → $(\alpha,n)^{29}Si$ / $(p,\gamma)^{27}Al$ → $(\alpha,p)^{30}Si$ / $(n,\gamma)^{28}Al(\beta^-)^{28}Si$
^{23}Na → $(p,\alpha)^{20}Ne$

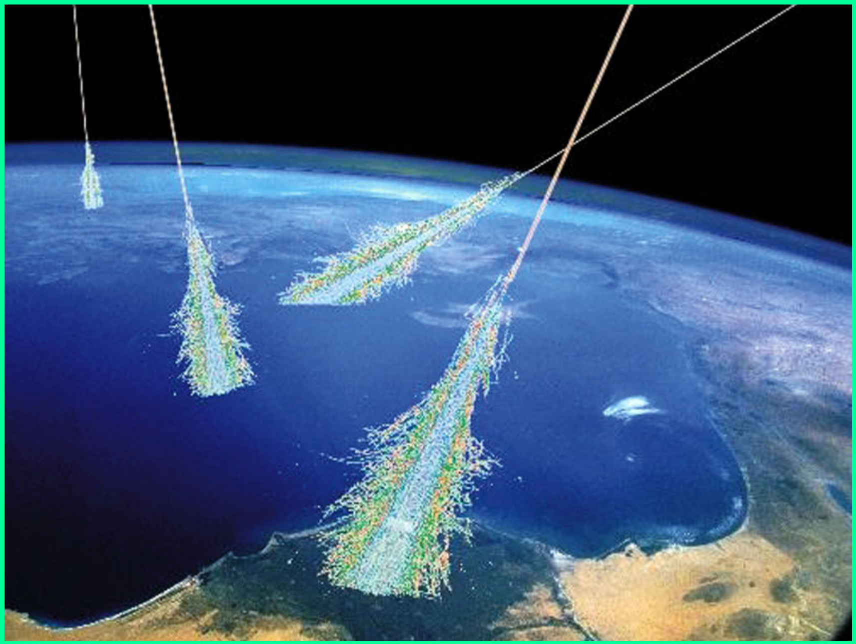
$^{22}Ne(\alpha,n)^{25}Mg$

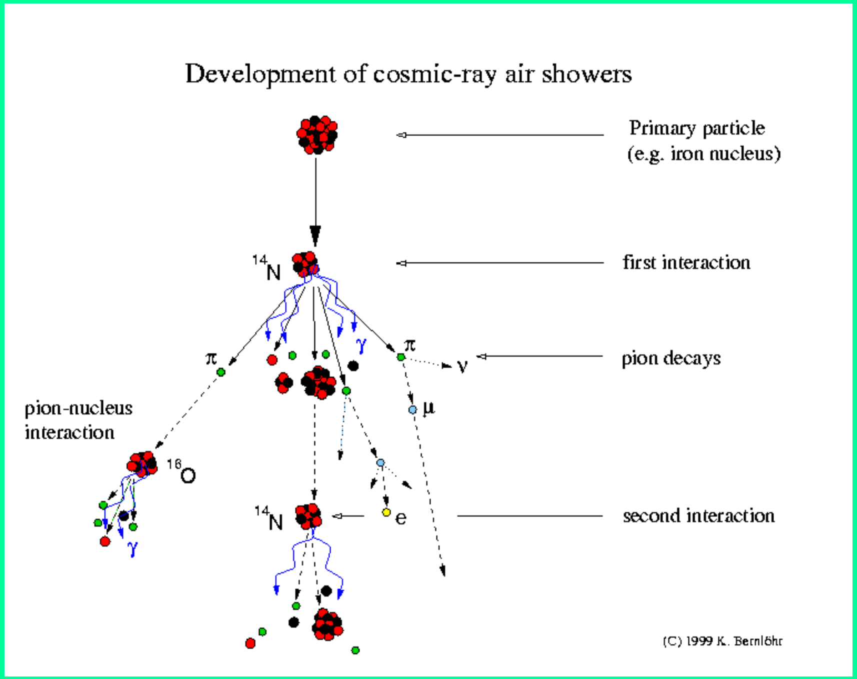
$^{20}Ne(n,\gamma)^{21}Ne$

$^{28}Si(n,\gamma)^{29}Si(n,\gamma)^{30}Si$

$^{25}Mg(n,\gamma)^{26}Mg$

Background component: cosmic rays





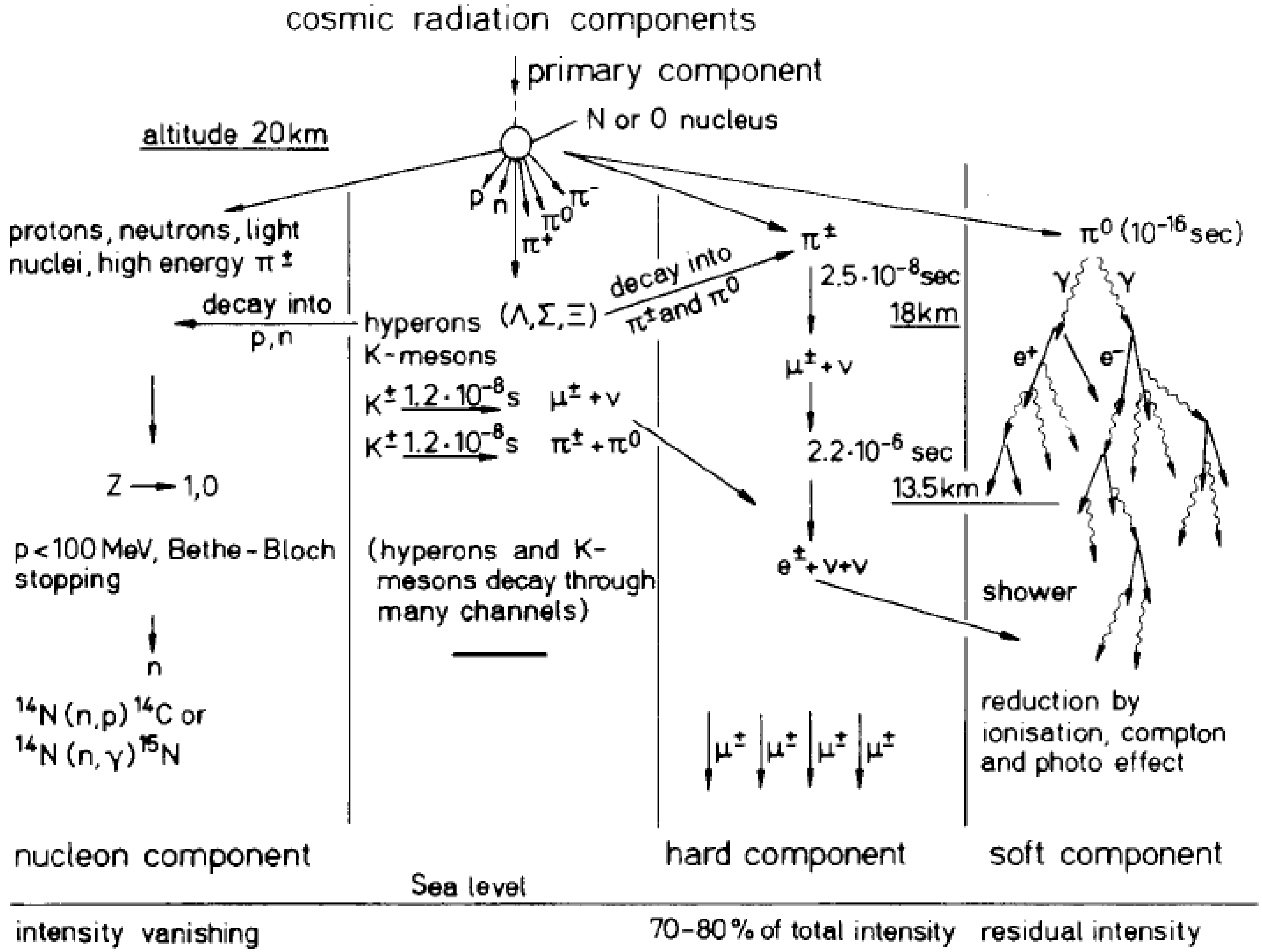


Fig. 1. Reaction scheme of cosmic rays with the atmosphere of the earth.

Digging for Science

Rolfs & Rodney 1985

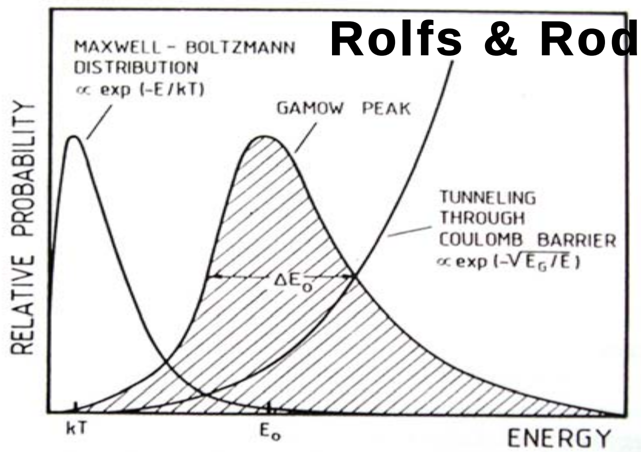


FIGURE 4.6. The dominant energy-dependent functions are shown for nuclear reactions between charged particles. While both the energy distribution function (Maxwell-Boltzmann) and the quantum mechanical tunneling function through the Coulomb barrier are small for the overlap region, the convolution of the two functions results in a peak (the Gamow peak) near the energy E_0, giving a sufficiently high probability to allow a significant number of reactions to occur. The energy of the Gamow peak is generally much larger than kT.

Why going underground?

- **Searching for rare events physics→ background level achieved → develop strategies for background rejection+ state-of-the-art ultra-low background technique**

  ↓

  deep underground site to avoid cosmic radiation + technology to deal with low sources of background

Underground background suppression (LUNA)

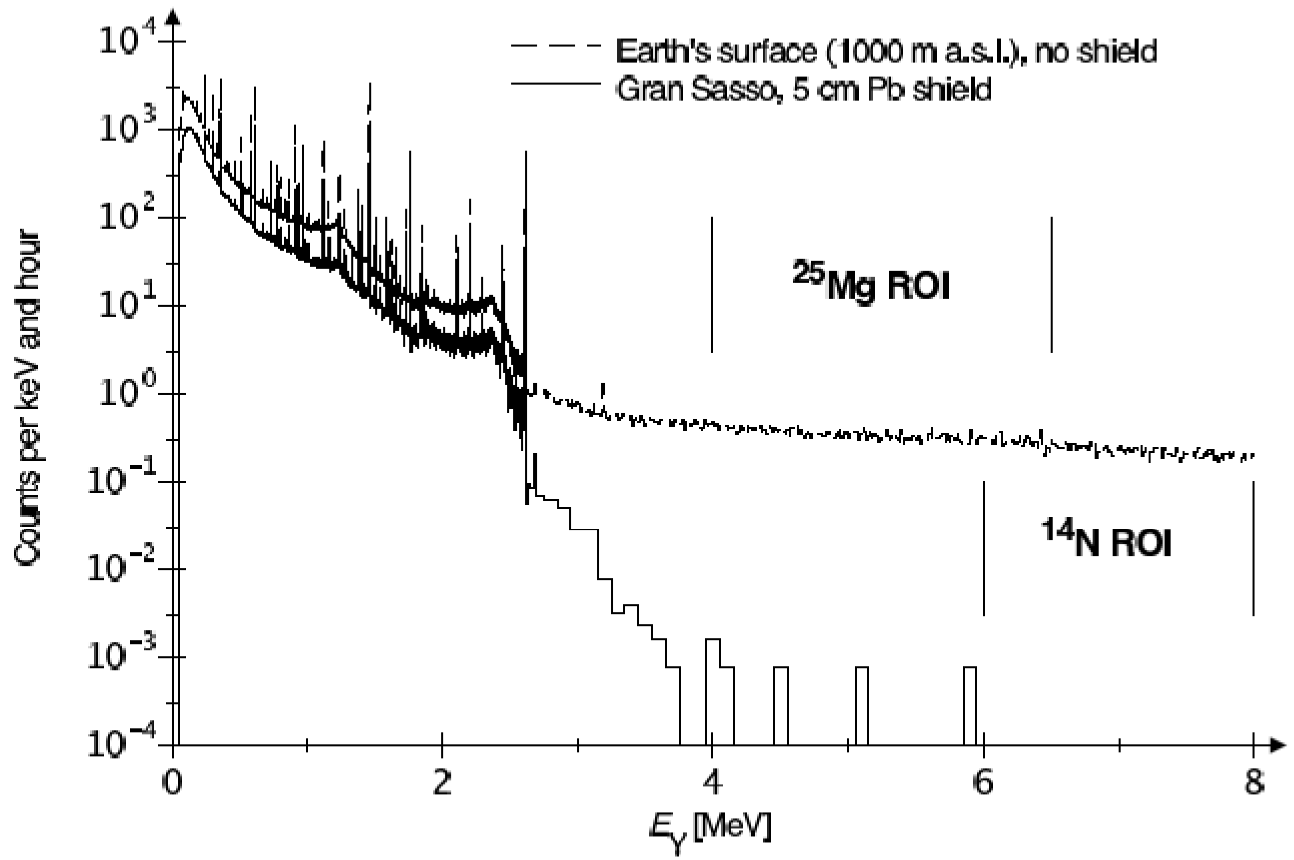


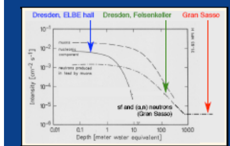
Fig. 2. Laboratory γ background as seen with the germanium detector of setup A at the earth's surface (1000 m above sea level) and inside the Gran Sasso underground facility.

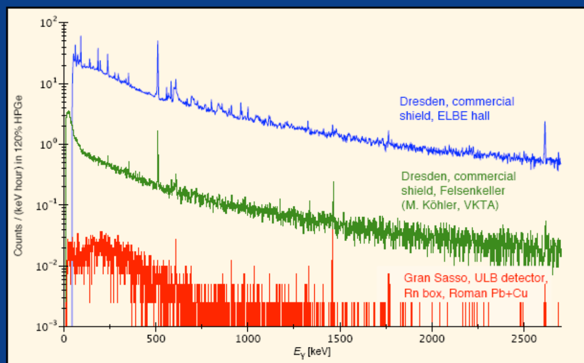
Background reduction effects

LUNA

HISTORY

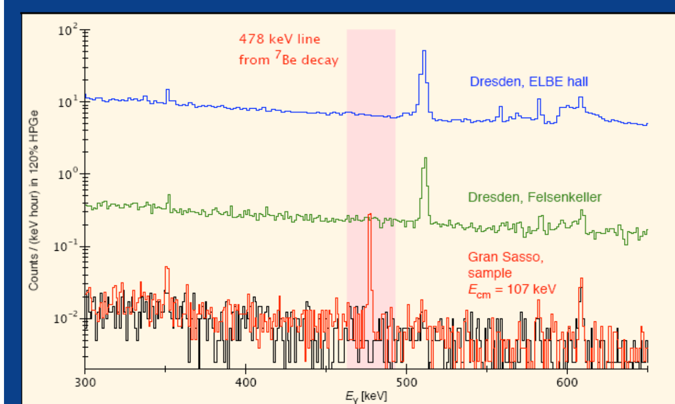
Laboratory background in gamma detectors underground





Forschungszentrum Dresden Rossendorf | Institut für Strahlenphysik 18 January 2007 | Daniel Bemmerer: Light nuclei deep underground | 1 ← 7 → 26

LUNA $^3He(\alpha,\gamma)^7Be$ experiment: Phase I, detected ^7Be activity



Activated ^{7}Be samples of 0.8 — 600 mBq

This example: 25 mBq

Forschungszentrum Dresden Rossendorf | Institut für Strahlenphysik 18 January 2007 | Daniel Bemmerer: Light nuclei deep underground | 1 ← 11 → 26

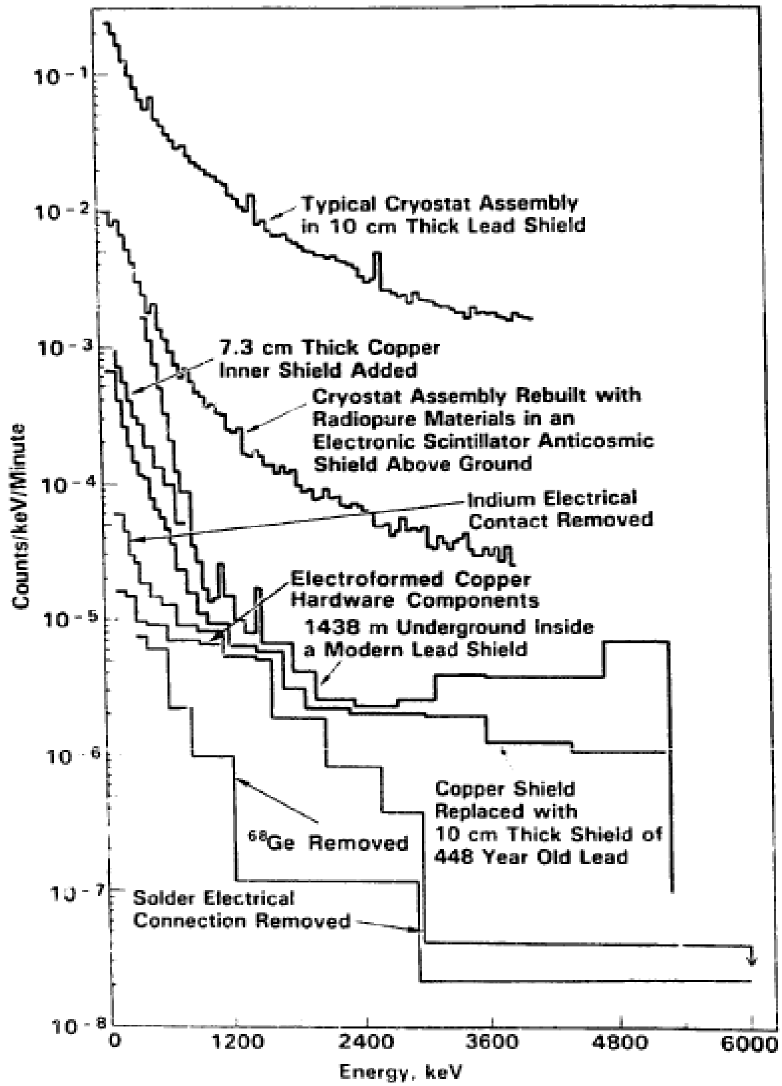
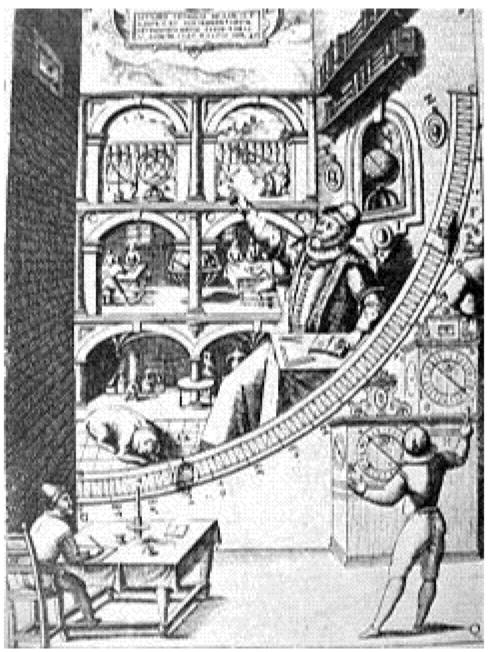


Fig. 1. Improvements in low-background technology.

On the shoulders of giants

Underground research is emerging as a unique and irreplaceable component of science



There can be little doubt that increased effort in this area will yield tremendous scientific dividends, including totally unexpected results.

Frontier Science: we need the depth (and ≥20 yrs access)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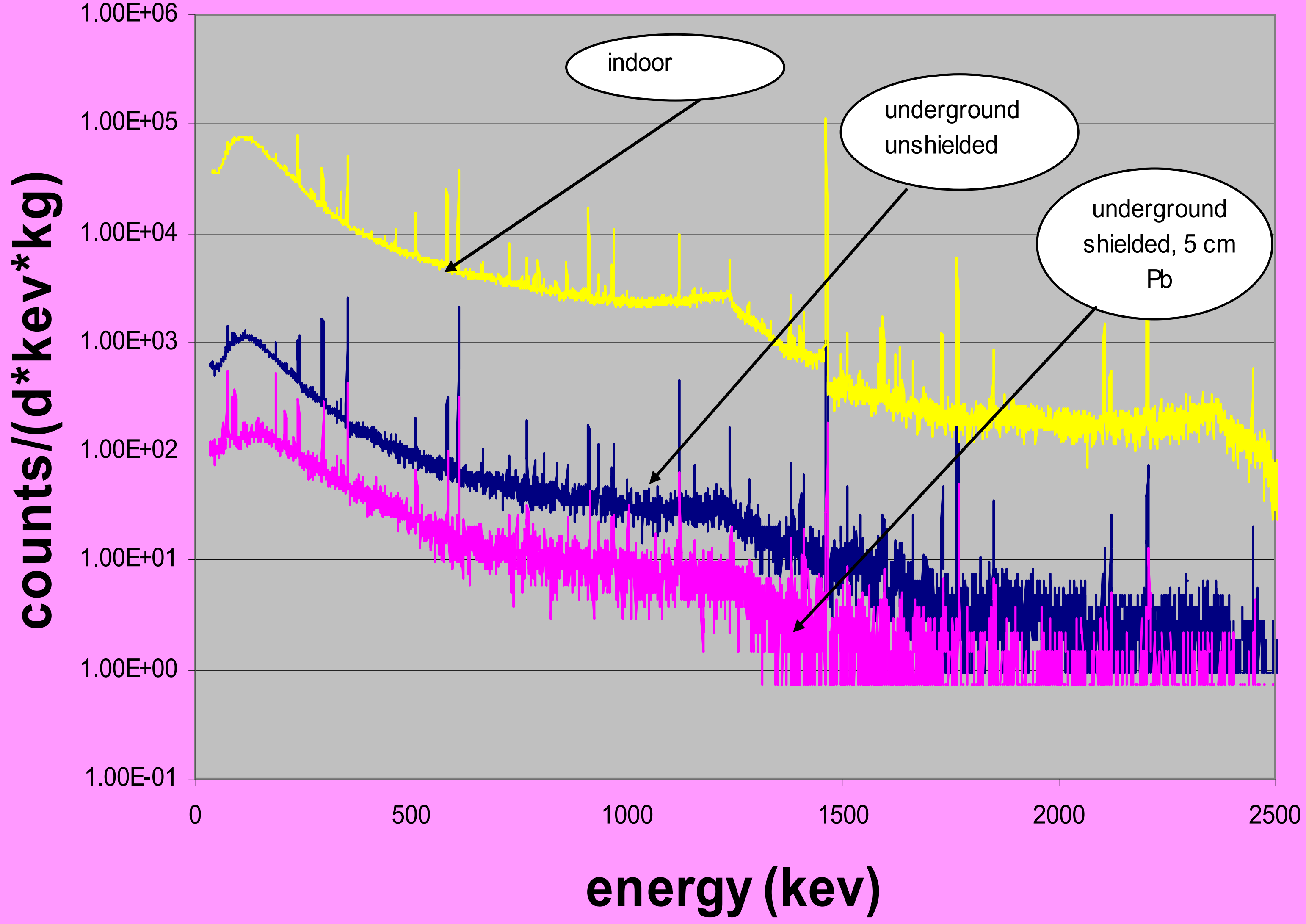
Google

Europe Underground Labs under ILIAS

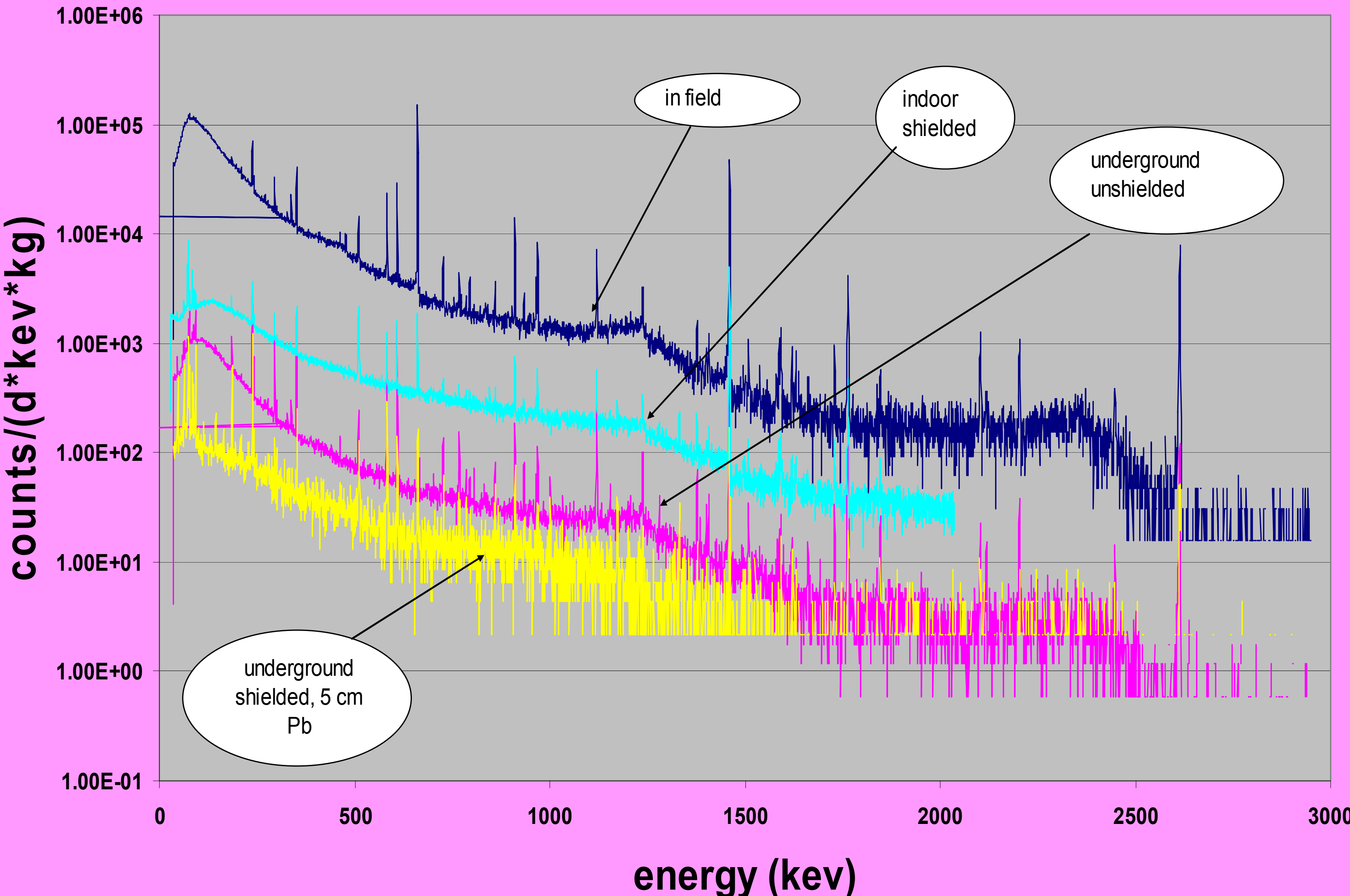
HH–NIPNE TANDEM accelerator : 8.5 MV (Bucharest)


Slanic Prahova
Unirea Hall

Slanic Prahova Background spectra collected with a CANBERRA GeHP detector with 22.2% rel. efficiency



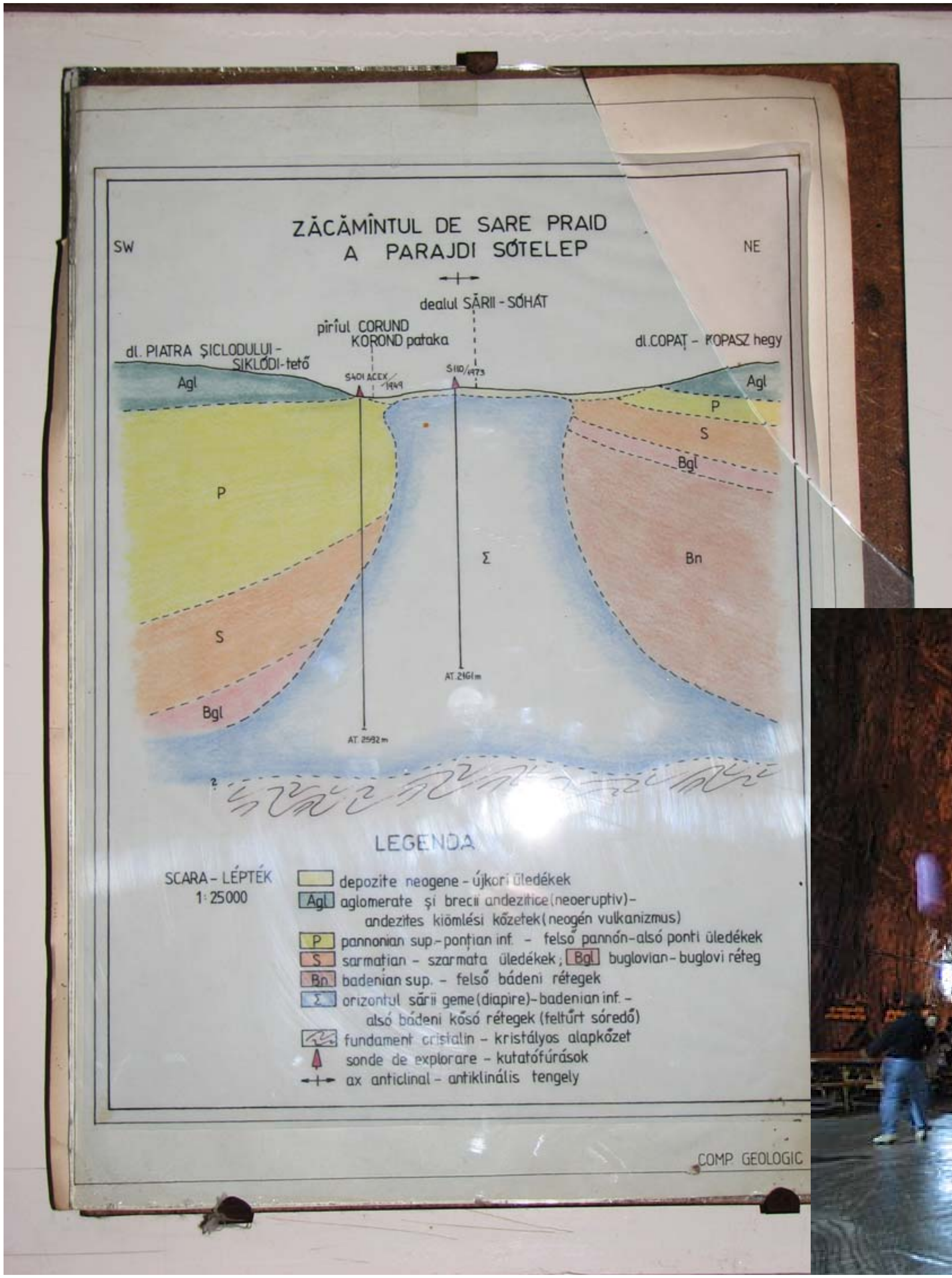
Slanic Prahova Background spectra collected with an ORTEC GeHP detector with 33% rel. efficiency



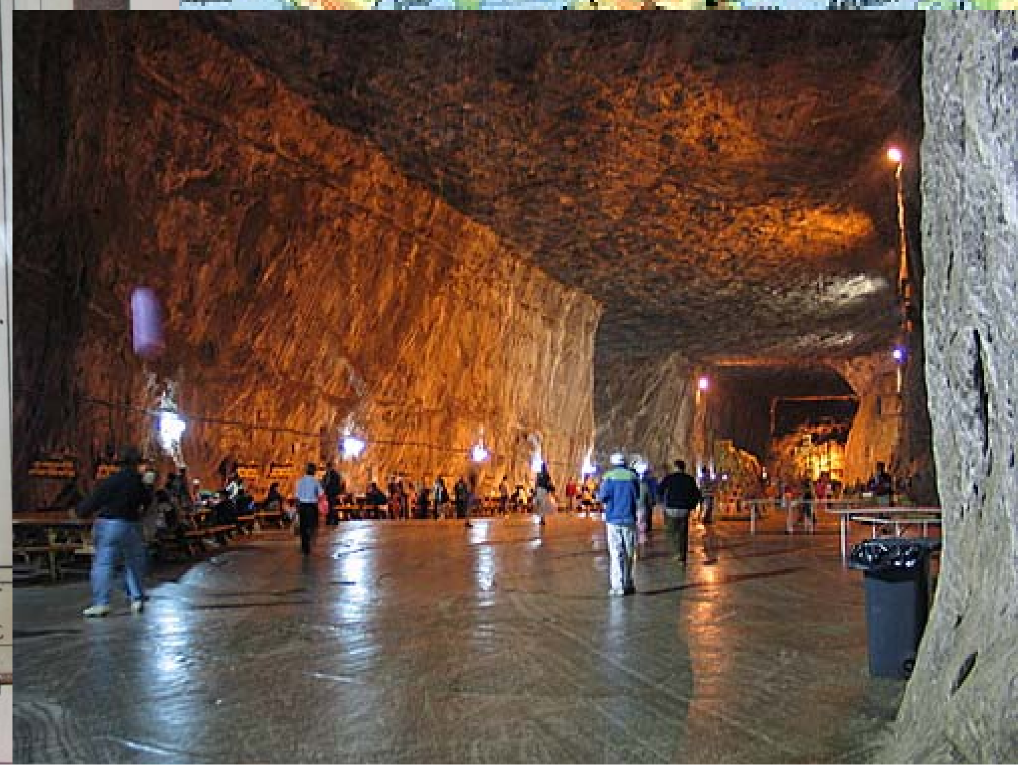
Gamma ray peaks in the background spectrum, collecting time=267500 s, ORTEC detector, 33% rel. eff., underground unshielded

Slanic Prahova

Isotope	Energy (k	cps		Isotope	Energy (k	cps
Pb-210	46,52	0,0025		Pa-228	911,23	0,0024
Pb-212	77,11	0,0201		Bi-214	934,05	0,0009
U-228	92,29	0,0132		Ac-228	968,90	0,0020
Ra-226	185,99	0,0072		Bi-214	1120,28	0,0041
Ac-228	209,40	0,0004		Bi-214	1155,19	0,0004
Pb-212	238,63	0,0273		Bi-214	1238,11	0,0016
Tl-208	277,36	0,0024		Bi-214	1280,96	0,0004
Pb-214	295,22	0,0134		Bi-214	1377,65	0,0011
Ac-228	328,00	0,0004		Bi-214	1407,98	0,0011
Pa-228	338,32	0,0011		K-40	1460,75	0,0158
Pb-214	351,99	0,0207		Bi-214	1509,19	0,0005
Pa-228	463,00	0,0008		Bi-212	1620,56	0,0003
Tl-208	510,72	0,0028		Bi-214	1661,28	0,0003
Tl-208	583,14	0,0064		Bi-214	1729,60	0,0007
Bi-214	609,32	0,0194		Bi-214	1764,51	0,0037
Bi-214	665,45	0,0014		Bi-214	1847,44	0,0005
Bi-212	727,17	0,0011		Tl-208	2103,47	0,0004
Bi-214	768,36	0,0017		Bi-214	2118,54	0,0003
Pb-214	785,95	0,0008		Bi-214	2204,12	0,0009
Bi-214	806,17	0,0004		Bi-214	2447,71	0,0004


ZĂCĂMÎNTUL DE SARE PRAID
A PARAJDI SÓTELEP
SW
NE
dealul SĂRII - SÓHÁT
pirîul CORUND
KOROND pataka
dl. PIATRA ŞICLODULUI -
SIKLÓDI-tető
dl.COPAŢ - KOPASZ hegy
Agl
P
S
Bgl
Bn
Σ
AT. 2592 m
AT. 2161 m
LEGENDA
SCARA - LÉPTÉK
1:25000
depozite neogene - újkori üledékek
aglomerate şi brecii andezitice (neoeruptiv) - andezites kiömlési kőzetek (neogén vulkanizmus)
pannonian sup.-pontian inf. - felső pannón-alsó ponti üledékek
sarmaţian - szarmata üledékek ; buglovian - buglovi réteg
badenian sup. - felső bádeni rétegek
orizontul sării geme (diapire) - badenian inf. - alsó bádeni kősó rétegek (feltűrt sóredő)
fundament cristalin - kristályos alapkőzet
sonde de explorare - kutatófúrások
ax anticlinal - antiklinális tengely
COMP. GEOLOGIC

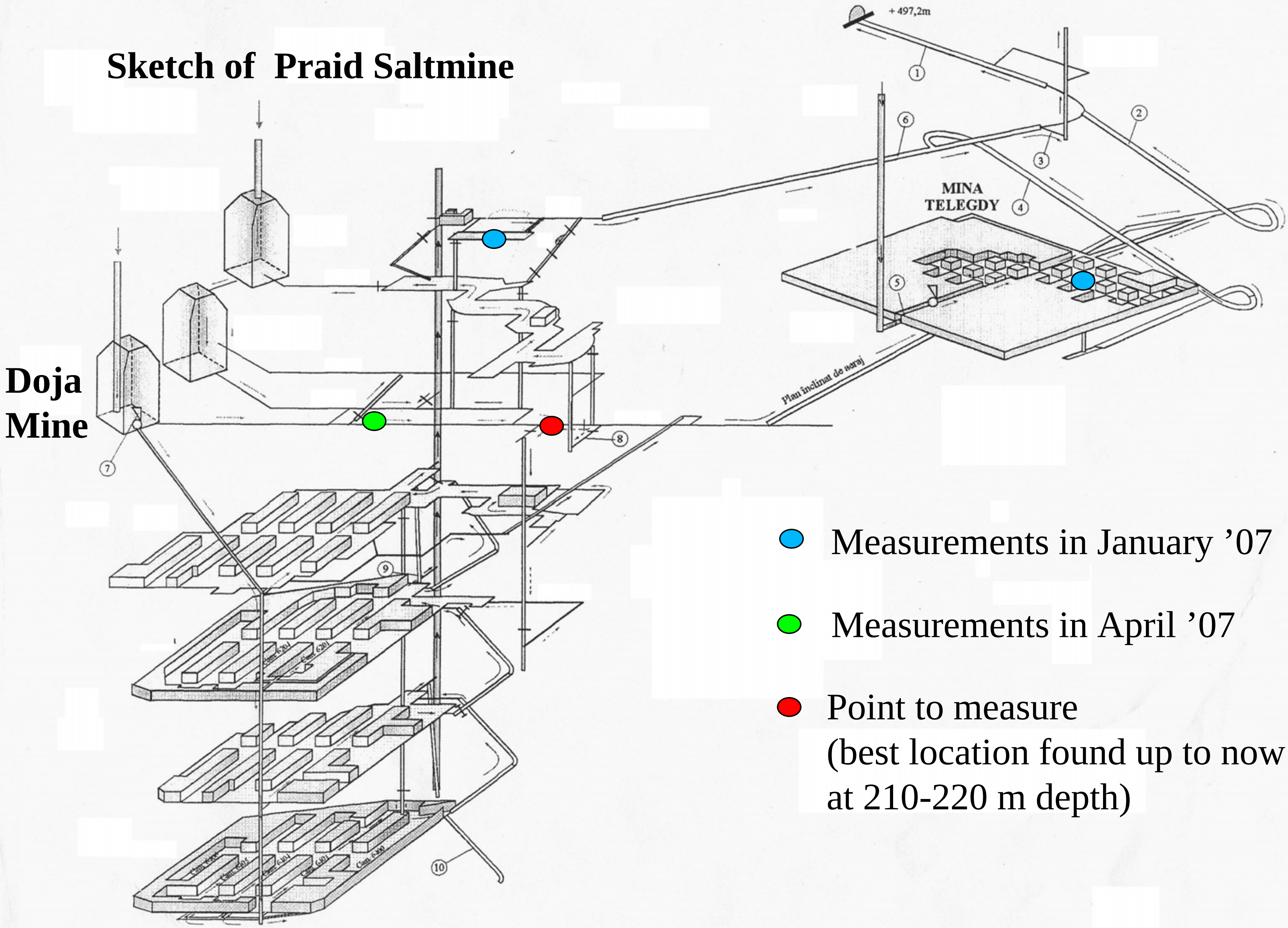

Sovata
Praid
SLOVAKIA
HUNGARY
ROMANIA
BULGARIA
ITALY
Budapest
Beograd
Sofia
Bucureşti
Zagreb
Napoli
Bari



Praid values

- Temperature: ~17 ^{o}C
- High air purity
- Relative high air humidity: 71%
- condensed vapours: NaCl, Ca^{2+}, Mg, K, Na, I, Br,..
- High CO_2 concentration: 0.1-0.3%
- Negative air ionization: $^{222}Rn(1.5\text{-}1.9 \times 10^{-13}$ Ci/l)
- pH low: 6.5-6.9 (acid character)
- Oxygen partial pressure is bigger by 2.07%

Sketch of Praid Saltmine



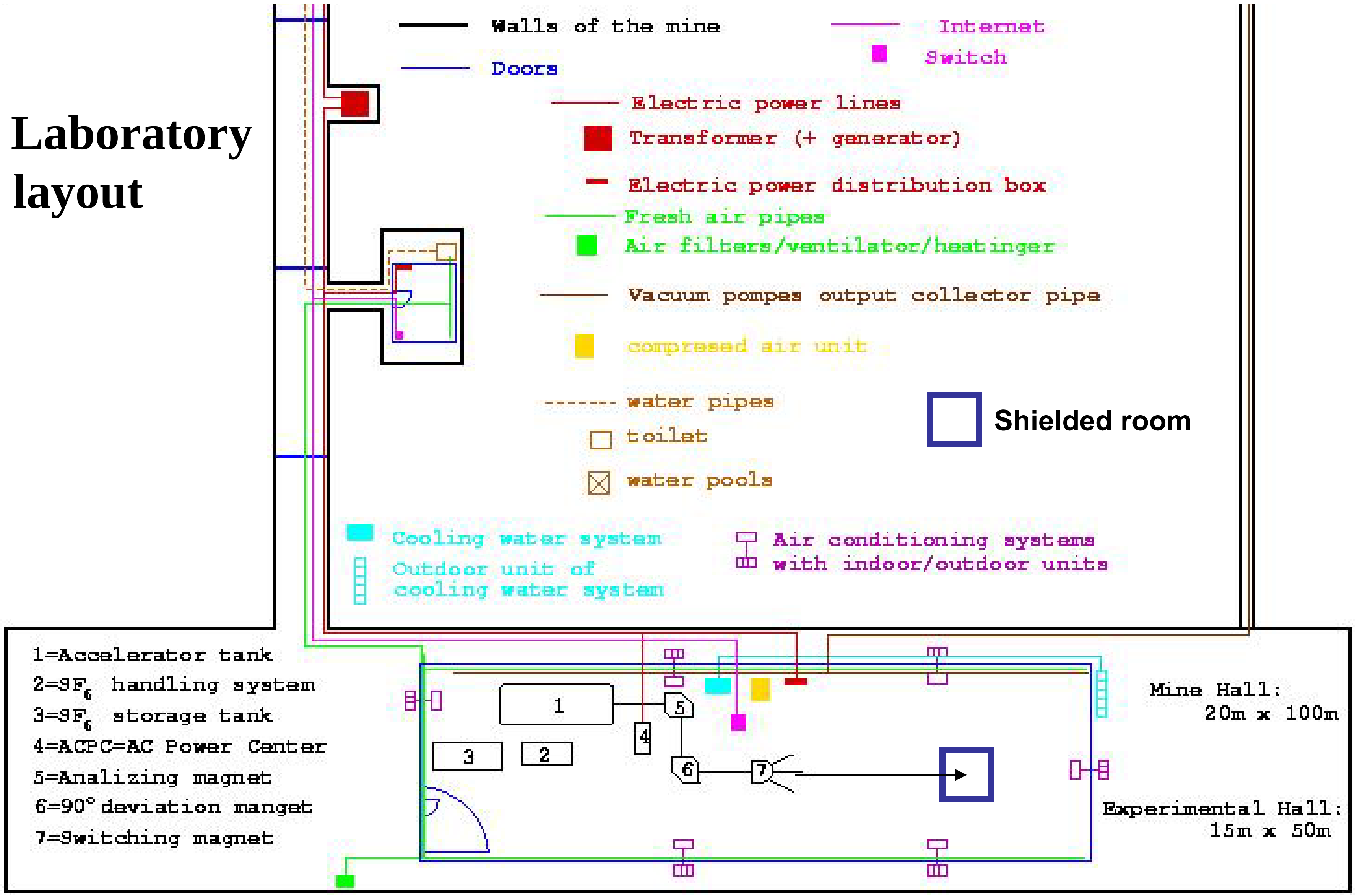
- Measurements in January ’07
- Measurements in April ’07
- Point to measure (best location found up to now at 210-220 m depth)

Requirements for searched location to install the accelerator :

- **Deepest possible**
- **Lowest possible background**
- **Access with truck (transport accelerator tank)**
- **Surface : min. 1000 m^2**
  max. "not huge" (to handle SF_6 gas in case of accidental release)
- **Height : min. 5 m**
  max. –
- **Not in use for other purposes**

To keep in mind: is rather cheap to make new tunnels and cavities in saltmine but could take time

Laboratory layout



One specific problem: the "convergence" of salt walls with up to 1 cm/year !

=> Adjustable supports for experimental hall and periodical realignment

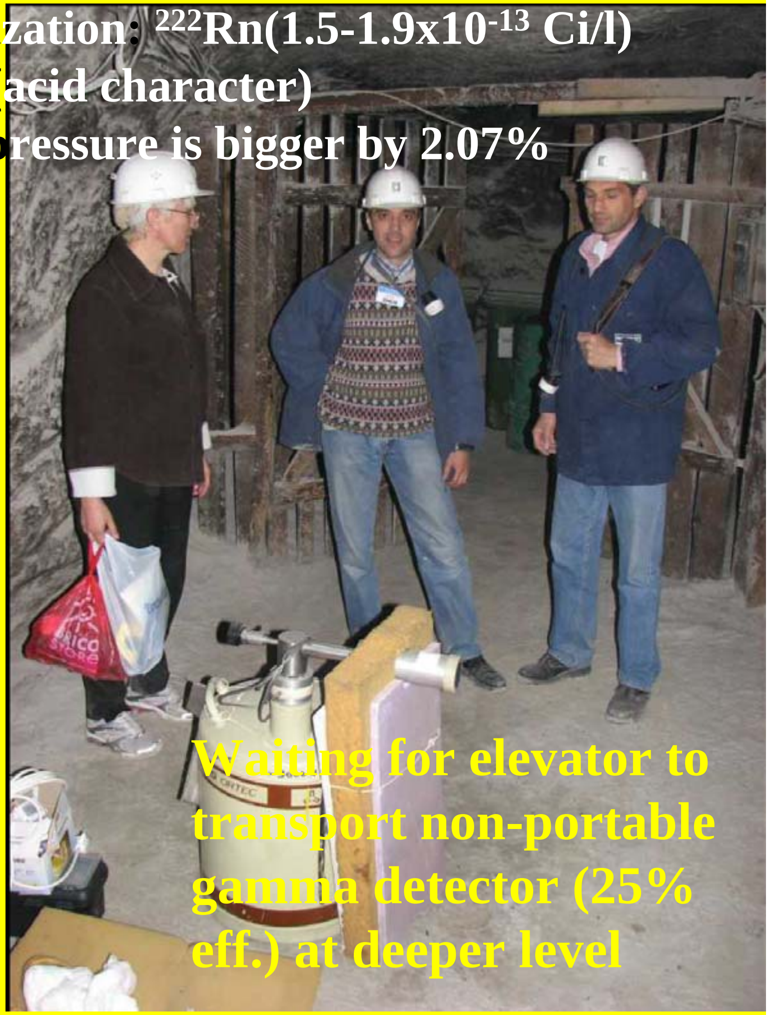
Project costs

1. Underground building and utilities	2.0 MEuro
2. Surface building for offices and worshops	0.3 MEuro
3. Accelerator and its installation/commissioning	5.0 MEuro
4. Infrastructure for experiments	1.6 Meuro
TOTAL:	**8.9 MEuro**

Project duration: 4 years
start: 2008 hopefully

- **Temperature: ~17 ^{o}C**
- **High air purity**
- **Relative high air humidity: 71%**
- **condensed vapours: NaCl, Ca^{2+}, Mg, K, Na, I, Br,..**
- **High CO_2 concentration: 0.1-0.3%**
- **Negative air ionization: ^{222}Rn(1.5-1.9×10^{-13} Ci/l)**
- **pH low: 6.5-6.9 (acid character)**
- **Oxygen partial pressure is bigger by 2.07%**

Portable gamma detector used in January (33% eff.)



Waiting for elevator to transport non-portable gamma detector (25% eff.) at deeper level

Gamma spectroscopy results January 2007
33% eff

zone	30-3000 keV		time	2620-3000 keV	
	rate(cts/sec)	err(cts/sec)	(sec)	rate(cts/sec)	err(cts/sec)
Praid mine, orizont 60, detector in the center of the hall	*10.9916*	*0.0663*	*2501*	*0.0188*	*0.0027*
Praid mine, orizont 60, partial salt bricks shield	*4.9316*	*0.0248*	*8000*	*0.0053*	*0.0008*
Praid mine, orizont 60, detector close to the right wall	6.4643	0.0302	7109	0.0058	0.0009
Praid mine, orizont 60, detector close to left wall	8.1064	0.0403	5000	0.0016	0.0006
Praid mine, orizont 60, detector close to back left wall	13.5743	0.0583	4000	0.0030	0.0009
Praid mine, Telegdy, detector in the right center hall	23.9753	0.1264	1500	0.0133	0.0030
Praid mine, Doja mine, corridor near elevator	12.3000		240180	0.0006	0.0001
ground level (Sovata-Praid)	113.2504	0.1065	9989	0.0449	0.0021

Consistent results from TL dosimetry

Detectors type: GR200A

Exposure time: 107 days (102 inside mine)

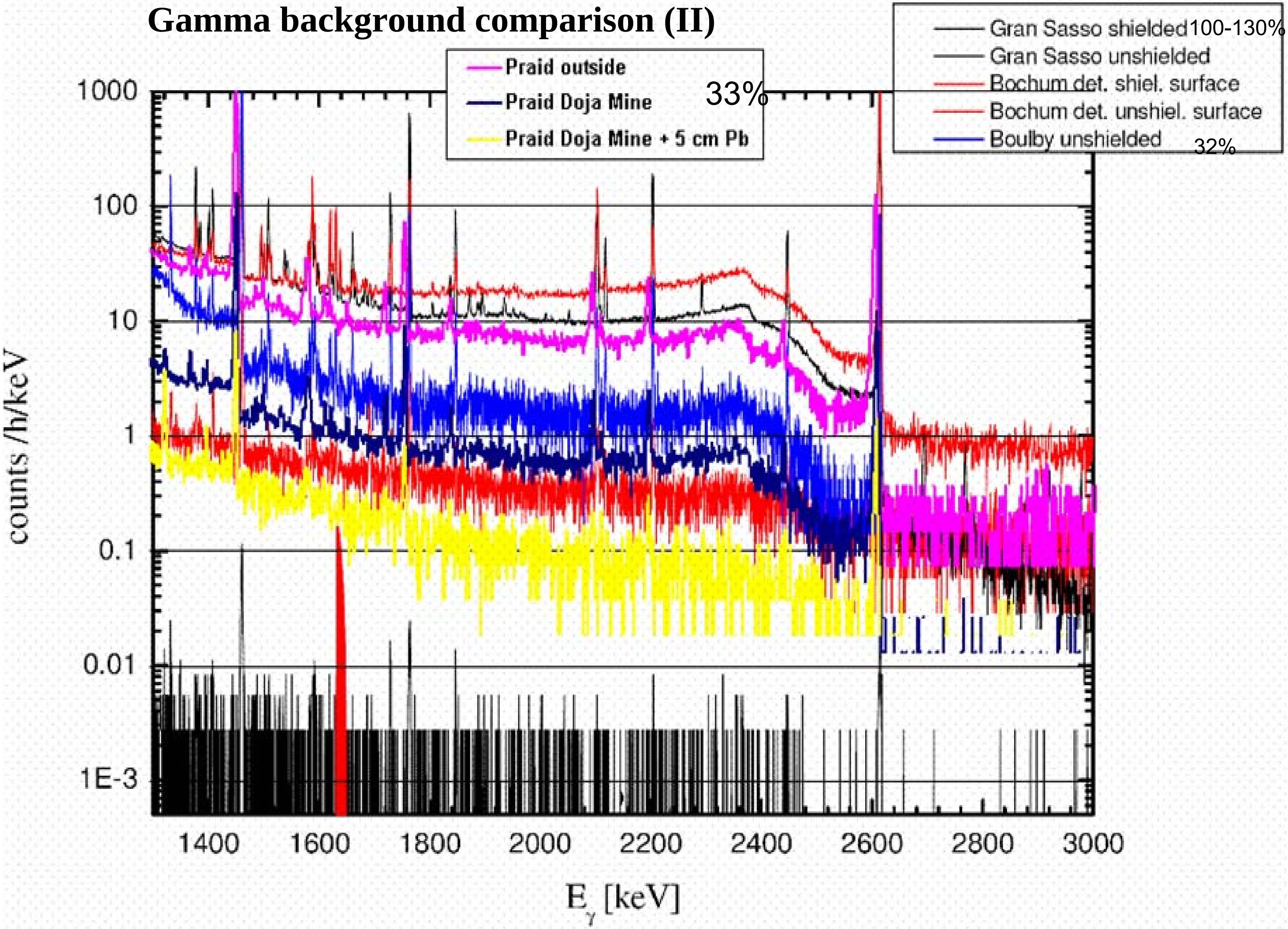
Telegdy Hall: 3.86 +/- 0.23 nSv/h

“Orizont 60” Hall: 2.76 +/- 0.17 nSv/h

Ground level: 55.1 +/- 0.7 nSv/h

IFIN-HH Bucharest: 73.3 nSv/h

Gamma background comparison (II)



April 2007 Ge detector 25% eff

Spectrum	Conditions	Time(sec)	2650-4650keV(cts/s)	609keV(cts/s)	1460keV(cts/s)	2614keV(cts/s)
praid_b1	I	240180	2.25E-03	2.31E-01	1.51E-01	1.90E-02
praid_b2	I&Pb	166835	2.05E-03	2.18E-01	8.81E-03	1.94E-03
sova_b2	O&Pb	41179	4.64E-02	1.02E-02	1.03E-01	2.63E-02
sova_1	O	43044	5.86E-02	4.40E-02	1.38E+00	2.29E-01

HP Ge - Detector

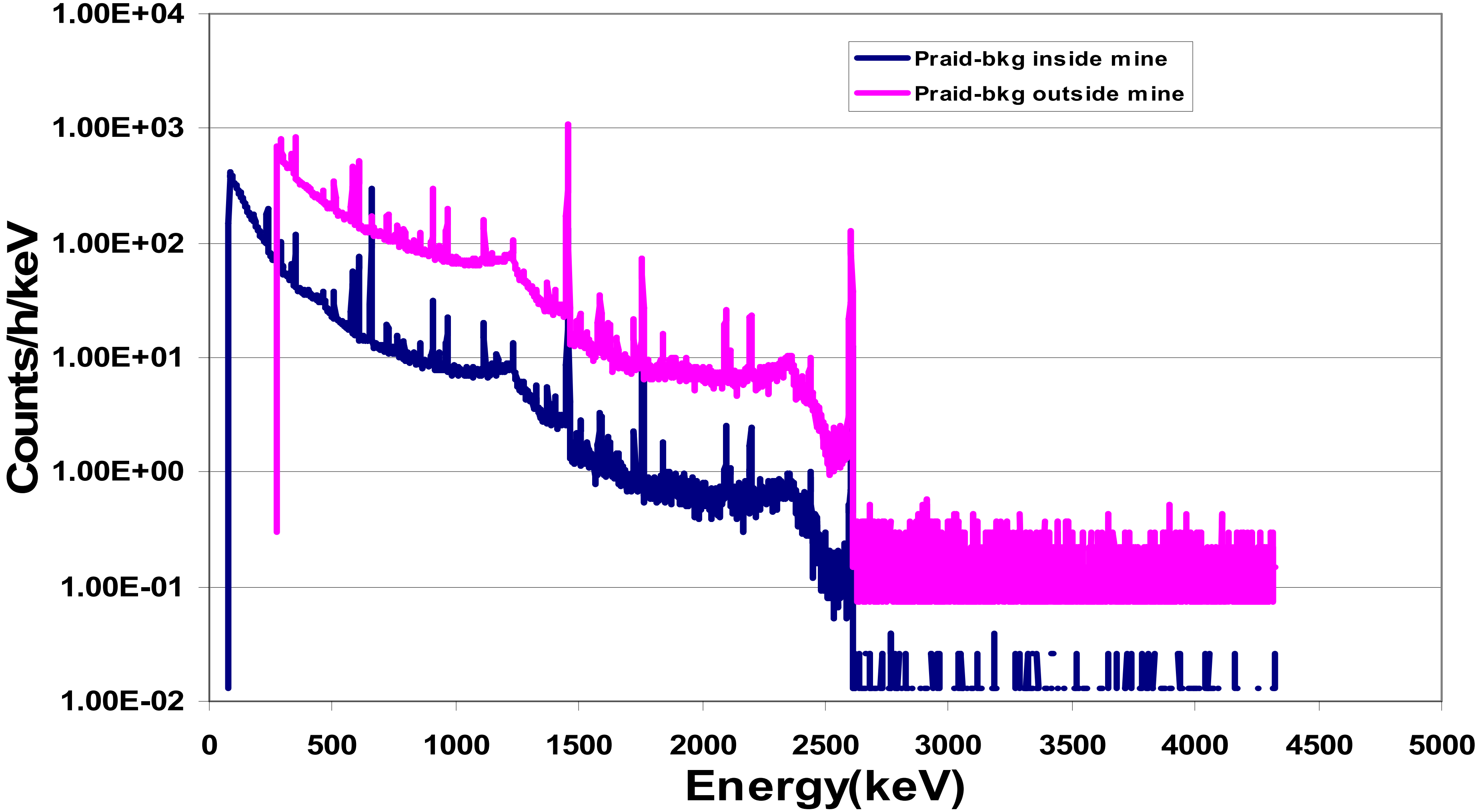
LNGS underground = 0.0002cts/s in 3MeV.. 8MeV

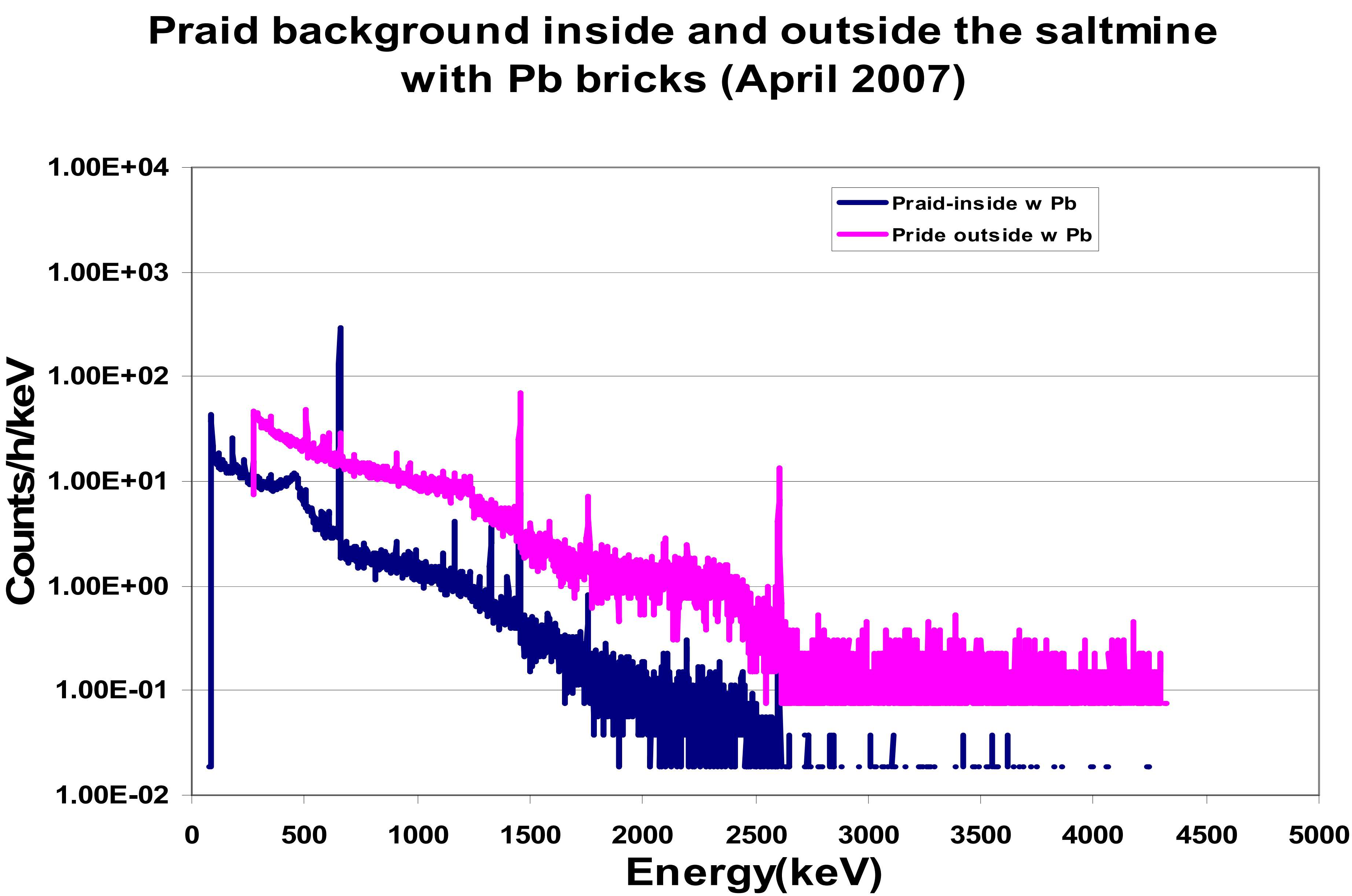
Ge detector (Romania)
Praid Underground = 0.00353±0.00015 cts/h/keV

Facilities to be developed

- Ion sources
- Recoil separators
- Targets
- Detectors
- Data Acquisition systems

Background inside and outside the salt mine without Pb bricks (April 2007)

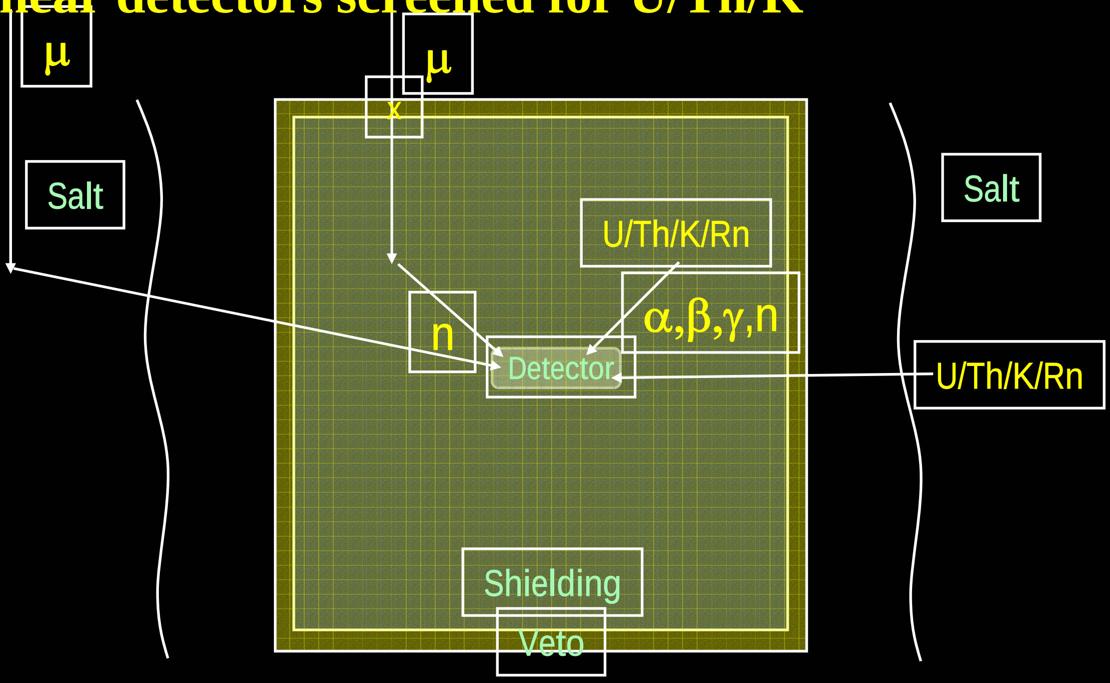




Praid background inside and outside the saltmine
with Pb bricks (April 2007)
Praid-inside w Pb
Pride outside w Pb
Counts/h/keV
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Energy(keV)

Layered shielding (reduce γ, β, neutrons)
Cu walls (cleanest material)
Thin “mu-metal” magnetic shield
Inner polyethylene (further neutron moderation)
Outside Pb & inner “ancient” Pb (low in ^{210}Pb)
Outer polyethylene (main neutron moderator)
All materials near detectors screened for U/Th/K

FUTURE



Active Veto (reject events associated with cosmics)
Thick plastic scintillator veto wrapped around shield
Reject residual cosmic-ray induced events

Values

Ogoya (Japan) 135m depth: muon flux $5 * 10^{-5}/cm^2/sec$

Oto Cosmo (Japan) over 400m depth: Rn level 10 Bq/m^3

Praid (Romania) : Rn level 6 Bq/m^3

Ogoya (Japan): neutron flux $2\text{-}4 * 10^{-5}$

Praid (Romania): U <10ppb or $133 * 10^{-3} Bq/cm^3$ or Bq/g

Boulby (UK): U ~10-400ppb

What are high purity materials?

Purity level	Common usage
99.9%	High Pure (3 nines purity)
99.95%	Analytical Grade
99.99%	Spectroscopically Pure
99.9999%	High Pure (6 nines purity)

Conclusions

There is a clear need for a new (or more such) underground accelerator based laboratory for nuclear astrophysics research in Europe.

Built in a saltmine, at 200-300 m depth, it will be best suited to host a gamma array of Ge detectors for reaction cross section measurements down to relevant energies for astrophysical processes.

IFIN-HH has the technical and scientific expertize to build such a laboratory, and it could be an intermediary step for a larger and deeper underground laboratory.

Its creation in Romania and its success depends on INTERNATIONAL users.

Differencies

- Depth
- Environment
- Infrastructue
- Human infrastructure
- Tools (accelerators, detectors, shielding)

What stage we are now?

- Conceptual one
- Activities we did already: measurements, administrative stuff, financial funds

Next steps

- Project submision
- Companies to contact – designs to be done and accepted
- Digging
- Monitoring salt, water, seismic movements
- Construction inside and outside
- Buying the accelerator and the other stuff around
- Young people to start working on science projects

Collaborations

- Geology
- Seismology
- Rare metals
- Health/medicine

Problems we face

- Tourism people
- Environment people
- Passing salt mines from state property to private property
- Recently member of the UE (new problems)
- Salt movements
- Water infiltrations
- Soil intrusions